Mechanisms on Graphical Core Variables in the Design of Cartographic 3D City Presentations

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Abstract: Virtual 3D city models are increasingly used in geospatial planning and discussion processes. This is one reason that the effectiveness and expressiveness of the presentation form has to be investigated from a cartographic point of view. This investigation reaches from recording and modeling procedures for 3D city models to a semiotic model, which has to be adapted for the use of 3D. This contribution focuses on mechanisms on graphical core variables that play an important role for the precise geospatial information transmission with 3D. Methods of non-photorealistic rendering can be combined with cartographic requirements. By this means a new potential for the graphic design of cartographic 3D city presentations can be shown.

1 Introduction

Cartographic 3D visualization and virtual 3D worlds reach increasing importance in the communication process of space. By now, tools like WorldWind, Virtual Earth or Google Earth form important geospatial presentation methods in planning and discussion procedures. These tools support naïve geography and thus may enhance the specific transmission of geospatial information [Däßler 2002]. In addition communication theories support the assumption that 3D presentation forms establish a naïve information transmission for topographic issues [Egenhofer 1995].

The aspect of successful communication leads to perceptional and graphical design issues. If graphics are used for cartographic depictions, a clear perception and understanding of information content has to be ensured. This demand is also valid for dynamic 3D presentation methods, if these are used for cartographic tasks. Hence an extension of the traditional semiotic model or at least the influence of 3D mechanisms on the semiotic model of 2D cartography [Bertin 1982] has to be considered. Especially cartographic 3D city presentations with their massive occurrence of occlusion call for appropriate dedication of graphical values and design mechanisms instead of photorealistic depictions that often lead to areas of dead information pixels (depending on the resolution of transmitting interface). Whereas photorealistic renderings of virtual 3D city models occupy most of the graphical values, non-photorealistic approaches try to use variables and design mechanisms according to specific visualization tasks or uses.

This contribution focuses on design mechanisms in virtual 3D city presentations, which make use or influence graphical core variables. In order to enhance specific parts of 3D elements, to support psychological depth cues on Pseudo3D interfaces (computer displays, projections, ..) or to follow emerging needs to fit in certain statements, these design mechanisms have to be adopted in a controlled way. Some concepts of virtual 3D city presentations will give an idea of computer graphics requirements and possible use cases for the overall composition design. It's possibilities lead to the limitations of photorealistic renderings for cartographic information transmission. In addition the concepts also depend on the design procedures of virtual 3D cities, which result in various detailed reconstructions and therefore offer a usable composition design. For example building areas that result from the intrusion of streets will neither be applicable for building-wise textures nor any building-wise information attachment. The section of critical amount of graphical variables and design mechanisms uses a general structure of 3D-semiotics and describes the interplay of graphical variables and 3D design mechanisms. For example, lighting influences graphical variables of color and brightness. Approaches of non-photorealistic rendering (NPR) can then express methods of NPR according to its space modification, give several pictorial examples and describe main advantages. At last we can combine the approaches of non-photorealistic rendering with graphical variables and design mechanisms in 3D in order to show the potential for the design of cartographic 3D city presentations. The obvious surplus value of NPR for virtual 3D city models with cartographic design leads to future work in cartographic 3D city presentations.

2 Concepts of virtual 3D city presentations

The visualization concepts of virtual 3D city presentations use photorealistic and non-photorealistic methods. Photorealistic methods try to reconstruct reality in virtual space. Therefore several graphical variables are used for this simulation procedure and few potential is left for additional information coding. Additionally the high resolution and detailed nuances are often not perceptible and have to be aggregated anyhow. In opposite to that, non-photorealistic rendering, like cartoon rendering, offers precise control over colors, sizes, brightness, forms, etc. for appropriate information coding at various levels. Following credits show up the main limitations of photorealistic methods for virtual 3D city models.

Photorealistic visualization implies a number of limitations with respect to virtual 3D city models:

1. To produce convincing photorealistic depictions, complete data in high quality have to be processed, e.g., exactly matching façade textures and high-resolution aerial photography. The larger the virtual 3D city model, the higher the costs for data acquisition. In most cases, required data will not be available for a whole 3D city model. As a consequence, the images are faced by a breach of graphics style.
2. To incorporate thematic information (e.g., state of repair, average rental fees) into photorealistic depictions, the information needs to be visually

combined with the virtual 3D city model. This turns out to be difficult, because textured façades, roofs, and road systems dominate the image space.

3. To visualize complex information, photorealistic details increasingly interfere with a growing number of information layers.
4. To express objects of city models in different states, e.g., existing, removed, and planned buildings, photorealism does not offer a broad range of graphics styles to communicate these variations such as by sketchy and outlined drawings.
5. To generate compact depictions for displays with minimal capacities, e.g., on mobile devices, photorealism frequently fails due the visual complexity inherent to photorealistic images. For example, a scaled-down version of a digital photography has a drastically lower information level compared to a scaled-down version of a hand-drawn sketch of the same scenery.

These drawbacks and limitations are the main arguments for non-photorealistic rendering, which needs specific requirements of the virtual model. On one hand geometry should follow a clear structure/outline for a most expressive cartoon rendering and on the other hand an object-oriented data structure splits up the element in smaller parts that are individually render- and combinable. These main requirements for non-photorealistic rendering lead to the various design procedures for virtual 3D city models.

3 Design procedures for virtual 3D cities

The procedures to create virtual 3D cities vary from precise photogrammetry to block model extrusion and smart city algorithms. Each procedure results in a specific data model that allows for cartographic information preparation. Cartographic information preparation in this context of visualization focuses on the clear visibility on transmitting media, which enables unmistakable perception of the content. It describes the mightiness of data model to be adapted for visualization and thus mutated in generalization processes.

Main production processes for virtual 3D city models span various methods of airborne surveying and photogrammetry, terrestrial surveying with ground plan extrusion or smart city algorithms. Various methods of airborne surveying and photogrammetry make use of high detailed remote sensing, aerial photographs and laserscanning (LIDAR). Detailed *remote sensing*, if the resolution of satellite pictures is high enough, and *aerial photography* produce top view pictures that form a starting material for the analysis of ground plan. In addition stereoscopic methods allow to extract heights and therefore detailed structures of building roofs [Kraus 2007]. Because a manual evaluation with its pointwise recording is highly time consuming, semi-automated procedures were developed and can support the modeling of buildings and roofs [Kraus 2007]. As result a detailed and precise structure of buildings including roofs is offered, which is sufficient for flythrough's in very large scales. For its cartographic usage these data mostly have to be simplified, aggregated and their most important characteristics highlighted on most transmitting media. This has to be done because this high detailed information cannot be successfully transmitted with most of used scales in combination with low media resolution (displays). *Airborne laserscanning* delivers data with similar precision. But the general result, without any postprocessing, is a point cloud of single measurements in form of the regular raster of the laserscanner [Kraus 2007]. A first postprocessing leads to a covering hull of the recorded surface that does not include any objectwise information than the height. At least filtering and further postprocessing lead to a covering hull of single buildings that can be enhanced with further (meta)information. Similar to the results of aerial photogrammetry, laserscanning also requires generalization for most of transmitting media because of its detail richness.

Terrestrial surveying with ground plan extrusion uses building plots and the average height of buildings to reconstruct a building block by extrusion of its outline. This procedure cannot reconstruct the roofs. Therefore the virtual 3D city model resulting from this technique is a simple block model, which may be sufficient for many applications and analysis of districts at a medium scale level. Depending on the outline detail of buildings, simplifications have to be done to remove imperceptible details [Kada 2005]. The extrusion process is done automatically by delivered data (outline, height). Additionally, for reason of aesthetics synthetic roofs can be added by algorithms. These synthetic roofs will visualize main characteristics but not represent a reconstruction of real world objects.

Smart city algorithms use cell-based clustering to generate generalized 3D city models (Fig. 1 shows an example for a generalized virtual 3D city). The clustering bases on the infrastructure network and decomposes city areas into clusters. Therefore the infrastructure network uses an implicit hierarchy of network elements that is used to create generalizations at various scales [Glander and Döllner 2007]. As input data the infrastructure network is used for the clustering process. The height of clusters is then calculated by the heights of a 3D city model, which may be the result of laserscanning, aerial photography or similar. The infrastructure network uses weighting of its vectors to build up categories and thus follow a desired degree of generalization (DOG). According to a chosen weight and its selected polylines a cell structure can be computed [Glander and Döllner 2007]. By cartographic means this resulting cell structure of a virtual city is applicable for small scale applications. On account of the underlying 3D city model, which is used for the heights of clusters, and the hierarchical structure of infrastructure network various levels of generalization can be visualized. This characteristic of the smart city method seems to be most promising for cartographic applications that call for transmitting media adapted scales.

Besides building reconstruction at various scale levels the modeling of terrain is another part in topographic reconstruction that has to be considered. Data structures for terrain models span from regular grids to triangulated irregular networks (TIN) and regular grid with breaklines [Pfeifer 2002]. The modeling of terrain is lead by reduction of data size and modeling precision. In terms of visualization it is important that the virtual 3D city model and the virtual terrain model do not perceptibly diverge.

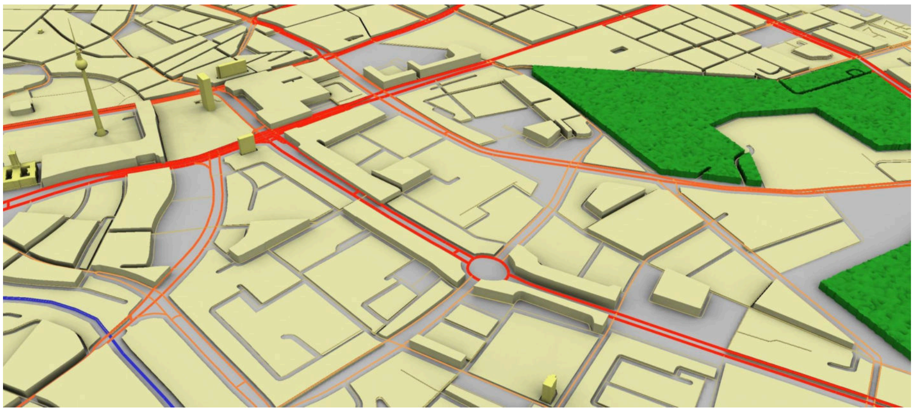

Fig. 1: A generalized 3D city model, Glander and Döllner 2007, p. 1.

The appropriate adaptation of graphical variables and design mechanisms for a cartographic visualization of virtual 3D city models will require an element-based structure that allows for element-based highlighting and information attachment. Furthermore the element-based structure enables scale-based or accuracy-based variations of the visualization. This demand for an element-based data-structure leads to the question, what kind of graphical variables and design mechanisms can be used in a virtual 3D environment? The following part will describe a general structure of 3D-semiotic and explain the interplay of graphical variables and 3D design mechanisms.

4 The critical interplay of graphical variables and 3D design mechanisms

Since cartography was involved in spatial information transmission usable graphical variables were a key factor for the graphical coding of information. By traditional means eight core variables can be identified. These are color, size, brightness, form, pattern, orientation and position (x,y) of the element [Bertin 1982]. Bertin splitted for x and y the variable of position in two parts. In combination with the graphical elements point, line, area, diagram and font, all imaginable coding can be realized. The extension of this traditional 2D semiotic structure with design mechanisms of 3D does not only lead to an extension, but to an extended semiotic structure for 3D (see Fig. 2). An extension of Bertin's list, like it was done by MacEachren (1995) with the variables crispiness, resolution and transparency, is not sufficient for the field of 3D cartography. An extension for 3D cartography means that all added design mechanisms of 3D massively influence the coding with graphical variables and elements. Therefore a semiotic structure for 3D includes variables of vision, composition and the psychological influences. Composition variables consist of global and element-wise 3D design mechanisms, graphical variables and graphical elements. These components will have mutual impact on each other.

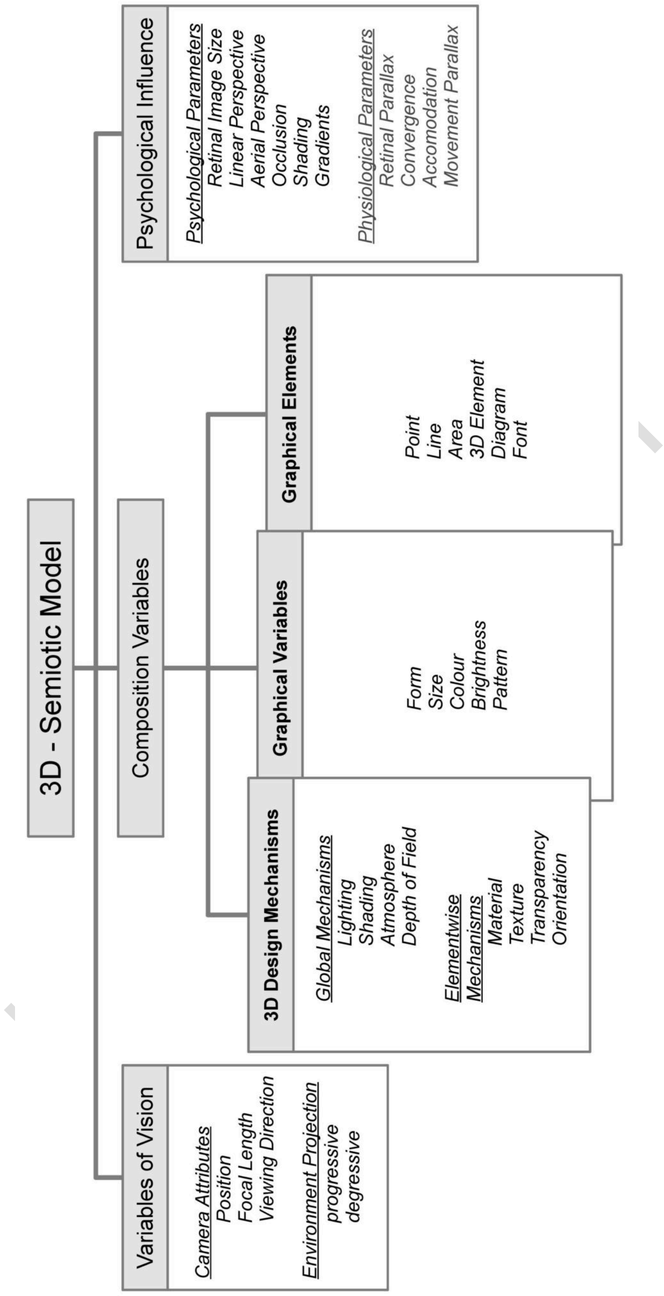

Fig. 2: Extended semiotic structure for 3D.

The original graphical variables of position are not identified as real variables in 3D anymore, because elements in the virtual 3D environment are almost fixed to their position. If an element changes its 3D position, then the relation to other elements is heavily influenced. In addition the cognitive impact of the 3D image will change, as perspective impressions and height relations will change with an elements position. For elements that are located in the 2D presentation plane and are not related with perspective consequences, variables of position in this 2D presentation plane are still valid. For example annotations in the 2D presentation plane will have to change their position in x,y picture space in order to stay perceptible.

The semiotic structure for 3D results in a confrontation of graphical variables and design mechanisms of 3D. As the core elements of graphical composition in 2D lead to a visual clear result on the transmitting media and their mutual impact in 2D is well defined [Bertin 1982, Brunner 2001, Hake and Grünreich 1994, Spiess 1996], a dynamic 3D map with its demand of intuitive geospatial information transfer, expands the semiotic model and shows up new graphical conflicts, which should be described by the following table:

Table 4.1: New graphical conflicts of 3D design mechanisms with graphical variables.

	A.Form	B.Size	C.Colour	D.Brightness	E.Pattern
Global Mechanisms:					
1.Lighting			C1	D1	
2.Shading	A2		C2	D2	E2
3.Atmosphere			C3	D3	
4.Depth of Field		B4			
Elementwise Mechanisms:					
5.Material	A5	B5	C5	D5	E5
6.Texture					E6
7.Transparency			C7	D7	E7
8.Orientation	A8				

A2: Shading influences an element's form, if for example hard shading makes it hard or impossible to differentiate between element and shadow. This situation becomes definitely urgent when shadows make use of whole grey values.

A5: Material influences form especially if “bump-mapping”- or “displacement mapping” techniques are used. These techniques apparently deform an element's geometry in order to simulate material surfaces.

A8: Orientation influences form because a perceptible form depends on an element's silhouette. If orientation changes, also the silhouette will change. For specific cases it will be needful to align elements according to their main characteristic. For example the front view of a church.

B4: Depth of field influences perception of size, because growing fuzziness prevents from concrete estimation, although the human cognitive system tries to come to an result by indications (linear perspective, gradients, ...).

B5: Material influences size, if “bump-mapping”- or “displacement mapping” techniques are used. These techniques apparently deform element's geometry in order to simulate material surfaces and therefore may change the size of elements.

C1: Lighting influences color in context with brightness distribution. The reaction of element's surface with lighting and the combination of lighting color with element's surface describe further influences. For example the distribution of brightness directly changes the saturation of color: the brighter an illuminated color area is, the more unsaturated the color will appear.

C2: Shading influences color as saturation and brightness of an element's color will be changed.

C3: Atmosphere influences color with its simulation of haze, which changes brightness and saturation of colors.

C5: Material and surface texture influences color if texture overlays and texture combinations create a new one. For example, a single colored ball in red that becomes combined with a mottling texture will change saturation and brightness of color according to the mottling pattern.

C7: Transparency influences color if it attenuates the opaque characteristic. Overlays with other elements become established and additionally change the allocation of colors.

D1: Lighting directly influences brightness as this is the main characteristic of light.

D2: Shading directly influences brightness as the change of grey values is how shadow works.

D3: Atmosphere influences brightness as the change of brightness is one part of haze simulation.

D5: Material and surface texture influences brightness when combinations of textures result in a new brightness.

D7: Transparency influences brightness as transparency changes reflexivity of the element's surface.

E2: Shading influences pattern if the forming and impact of shadow results in similar grey values as the pattern. Similar grey values then unite and create a new pattern.

E5: Material influences pattern when “bump-mapping” or “displacement mapping” apparently change the element's geometry. Therefore surface shadows are created and thus change original pattern.

E6: Texture influences pattern if texture combinations result in a new pattern.

E7: Transparency influences pattern, because new combinations become enabled with a partial transparent pattern.

The critical interplay of graphical variables and design mechanisms show that composition variables have to be precisely considered for cartographic 3D applications in order to find appropriate graphical expressions. However composition variables in 3D offer additional design mechanisms. The rendering of the virtual 3D environment provides relevant tools to incorporate and manipulate most graphical variables and design mechanisms. These rendering techniques are called non-photorealistic rendering (NPR).

5 Approaches of non-photorealistic Rendering

Non-photorealistic computer graphics denotes the class of depictions that reflect true or imaginary scenes using stylistic elements such as shape, structure, color, light, shading, and shadowing that are different from those elements found in photographic images or those elements underlying the human perception of visual reality (Fig. 3 shows an example). Most researchers agree that the term “non-photorealistic” is not satisfying because neither the notion of realism itself nor its complement, the non-photorealism, is clearly defined. Nevertheless, “non-photorealism” (NPR) has established itself as a key category and discipline in computer graphics starting around 1990. An introduction to concepts and algorithms of non-photorealistic computer graphics can be found in Strothotte and Schlechtweg (2002) as well as in Gooch and Gooch (2001).

Fig. 3: Example for an expressive rendering of a 3D city model.

5.1 A technical aspect of non-photorealistic rendering

Technically, non-photorealistic 3D rendering is implemented by redefining the geometry stage and rasterization stage of the standard 3D rendering pipeline using application-defined procedures, known as shaders, which implement geometric transformations, illumination calculations, and pixel shading. For example, the classical Phong illumination model (Phong 1975) can be substituted by a cartoon-like illumination shader, which reduces the number of shades per color. Furthermore, non-photorealistic 3D rendering takes advantage of multi-pass rendering, that is, they process a 3D scene description several times, generating and combining intermediate images into a final image. This way, for example, enhanced edges and shadows can be included in the overall rendering process. Furthermore, today’s programmable computer graphics hardware supports the implementation of non-photorealistic 3D rendering. Therefore, most techniques can be used in interactive or even real-time applications and systems.

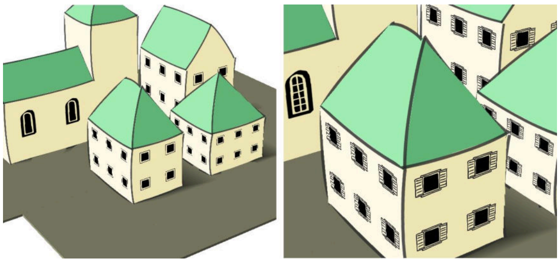

Fig. 4: Example for usage of NPR and Level of Detail adaptation, Döllner and Walther 2003, p. 6.

5.2 Combining graphical variables, design mechanisms and NPR

It seems obvious that non-photorealistic rendering with its toon-like visualization directly uses graphical variables and design mechanisms as these are used in cartography. Following descriptions list actual mechanisms that are usable in NPR today. If the parameters, which can be varied in NPR, mostly match with cartographic variables and mechanisms, then these values can be also employed for cartographic aims (Fig. 4). The combination of NPR and composition variables will then lead to cartography-designed virtual environments.

Generally characteristics of non-photorealistic 3D rendering include the ability to sketch geometric objects and scenes, to reduce visual complexity of images, as well as to imitate and extend classical depiction techniques known from scientific and cartographic illustrations. Fundamental techniques of real-time non-photorealistic 3D rendering address the following characteristics:

1. Lighting and Shadowing. The programmable rendering pipeline allows developers to implement new illumination models such as the model introduced by Gooch et al. (1998). In addition, real-time shadow techniques can be seamlessly integrated and, thereby, provide a valuable depth cue;
2. Coloring and Shading. Non-photorealism allows for vivid and domain-specific color schemes. Cartoon-like appearance is achieved by specialized color schemes such as tone shading;
3. Edges and Silhouettes. Edges as visually important elements can be treated as "first-class" objects in depictions, that is, they can be enhanced and stylized. Isenberg et al. (2003) give an overview of algorithms for outlines and silhouettes (Fig. 5);
4. Texturing. Texturing is used as a fundamental computer graphics operation (Haeberli 1990) to outline the principle curvature of surfaces, to simulate strokes using virtual brushes, to procedurally generate textures, and to implement image-based operations such as image overlays, image blending, convolution filtering, etc.

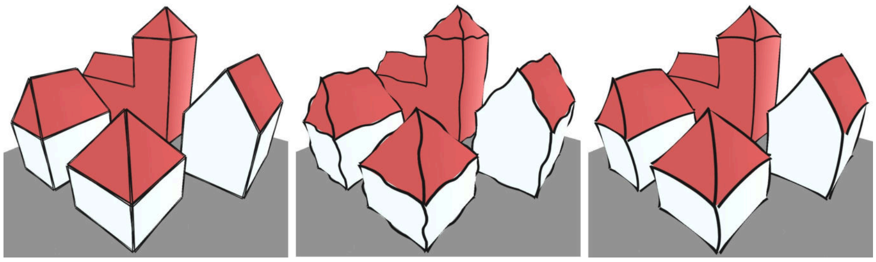

Fig. 5: Variations of edge visualization showing the potential of edge rendering in NPR.

This section can show that rendering mechanisms in NPR use the same composition variables and designing procedures as in cartography. Therefore this parameters can easily be adapted for cartographic needs. This means that geospatial information description can follow cartographic rules in order to result in an unmistakable information transmission.

6 Conclusion

This contribution focuses on mechanisms on graphical core variables in the design of cartographic 3D city presentations. This means that specific design mechanisms exist for the cartographic visualization of virtual 3D cities. The notion NPR describes these methods within the rendering process. Before these visualization methods can be adapted, appropriate virtual 3D city models have to be created in order to lead to a desired result. Unsuitable models may lead to unplanned artifacts in the rendering process that will represent non-important information. On that score recording methods (remote sensing, aerial and terrestrial measurements,...) and their post-processing have to be considered with the aim to use appropriate starting materials for cartographic visualization. Further graphical designing steps for cartographic 3D city presentations lead to the question if design mechanisms of 3D can be incorporated in the traditional semiotic model of cartography? Section 4 describes the critical interplay of graphical variables and 3D design mechanisms and results in an extended semiotic structure that is applicable for 3D. Because of the interplay of graphical variables and design mechanisms, conflicts can be identified and are shortly described in that section. The presented methods of non-photorealistic rendering in context with cartographic visualization show their close relation with composition variables. This clarifies the usage of NPR for cartographic visualization of virtual 3D cities.

Future research in this field has to focus on the usability of the extended semiotic model for 3D and the power of variables offered by NPR. In the end usability studies and user tests will show if these techniques can produce expressive and effective results for cartographic 3D city presentations.

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